Effects of roughage concentration in dry-rolled corn-based diets containing wet distillers grains with solubles on performance and carcass characteristics of finishing beef steers[1]

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ABSTRACT: Distillers grains and distillers solubles are by-products of grain fermentation used to produce ethanol and contain greater concentrations of NDF and ADF, compared with other grains and concentrates they replace in feedlot diets. Typical finishing diets in the United States contain 8.3% and 9.0% roughage. Therefore, it is plausible that the dietary concentration of roughage can be altered when distillers grains are included in feedlot diets. The effects of roughage concentration in dry-rolled, corn-based diets containing wet distillers grains with solubles (**WDGS**) were evaluated in steers ($n = 128$; initial BW = 339 kg), using Calan gates. Each diet was based on dry-rolled corn and contained 25% WDGS with coarsely ground alfalfa hay (**AH**), replacing corn at 2% (**AH-2**), 6% (**AH-6**), 10% (**AH-10**), and 14% (**AH-14**) of DM. Feed offered was recorded daily, orts were measured weekly, and BW was measured on d 0, 1, 35, 70, 105, 140, 174, and 175. After commercial harvest and chilling, carcasses were evaluated on-line with a beef carcass grading camera to assess marbling and yield grade traits. The data were analyzed using the Mixed Procedure of SAS, in which contrast statements were used to separate linear and quadratic effects of AH inclusion. Decreasing concentrations of AH in the finishing diet resulted in a tendency for a quadratic response ($P = 0.07$) in final BW, where BW increased from 2 to 6% AH inclusion but then decreased from 6 to 14% inclusion. Similarly, ADG from d 0 to end responded quadratically ($P < 0.01$), in which ADG increased from 2 to 6% yet subsequently decreased from 6 to 14% AH inclusion. Dry matter intake from d 0 to end increased linearly ($P = 0.02$) as AH inclusion increased in the diet, whereas G:F increased from 2 to 6% AH inclusion and then decreased linearly ($P < 0.01$) from 6 to 14% AH inclusion. Concentration of AH in the finishing diet did not affect HCW, marbling score, or the proportion of cattle grading USDA choice ($P \geq 0.18$). However, dressing percent and LM area did respond in a quadratic manner ($P < 0.02$), in which they decreased from 2 to 10% AH inclusion and increased from 10 to 14% AH in the diet. Yield grade and adjusted 12th rib fat responded quadratically ($P < 0.01$), in which both increased from 2 to 6% AH inclusion and decreased from 6 to 14% inclusion. Analysis of responses of G:F and ADG on AH predict the apex at 3% and 7% for G:F and ADG, respectively, when fed in diets containing 25% WDGS.

Key words: cattle, distillers grains, roughage level

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INTRODUCTION

Roughage source and concentration in traditional finishing cattle diets without by-products have been thoroughly investigated (Kreikemeier et al., 1990; Bartle et al., 1994) and reviewed (Galyean and Defoor, 2003; Galyean and Hubbert, 2012); however, fewer data are available on the most effective roughage concentration in finishing diets including by-products such as distillers grains. The evaluation of roughage concentration and source in feedlot diets became imperative in recent years because of the prolonged severe drought that occurred in the High Plains. During such periods, traditional roughage sources, like alfalfa hay (**AH**) and corn silage, were not only difficult to procure but extremely expensive (Galyean and Hubbert, 2012). Currently, wet distillers grains

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with solubles (**WDGS**) are common in finishing diets and they are relatively high in NDF and ADF, compared with other grains (Klopfenstein et al., 2008). Therefore, a reasonable consideration is whether the dietary concentration of roughage should be altered when WDGS is included in feedlot diets. In a study by Benton et al. (2007), feedlot diets contained 30% WDGS (DM-basis) and high-moisture corn or dry-rolled corn. Alfalfa hay was included at 4% or 8% of diet DM, in addition to corn silage, which was included at 6% or 12% of diet DM. Or, corn stalks were included at 3% or 6% of diet DM, relative to the control, with no added roughage. Adding roughage increased final BW, DMI, and ADG, with no effects on G:F compared with the control. Furthermore, increased roughage levels increased final BW, DMI, and ADG. Our hypothesis was that cattle performance (ADG and G:F) would be improved with <9% roughage in finishing diets. Therefore, our objective was to determine if altering the dietary roughage in finishing cattle diets with WDGS from the industry standard of 9% to 2%, 6%, 10%, and 14% would adversely affect cattle performance and carcass characteristics.

MATERIALS AND METHODS

The U.S. Meat Animal Research Center Animal Care and Use Committee approved these experimental procedures.

Cattle

One-hundred twenty-eight steers (338.9 ± 6.5 kg initial BW) were used during the 175-d study. The steers were a MARC II composite breed, consisting of one-fourth each Simmental, Gelbvieh, Hereford, and Angus. Upon weaning, steers were transported to an intensive cattle research area where they were sorted to 1 of 16 pens in a facility equipped with Calan-Broadbent electronic headgates (American Calan, Inc., Northwood, NH). After arrival, steers were given a 35-d adaptation to the headgate facility. The facility consisted of pens approximately 9 × 9 m, with a concrete floor and approximately one-third under a barn open to the south. Steers were transitioned to a finishing diet and trained to use individual Calan headgates during the 35-d period. The cattle were implanted [Revalor XS (200 mg trenbolone acetate and 40 mg estradiol 17β), Merck Animal Health, Summit, NJ] ~20 d before the start of the experiment.

Treatments, Experimental Design, and Routine Management

A completely randomized design was used with 4 dietary treatments beginning in June of 2011. Before the start of the experiment, cattle were stratified by BW and assigned to 1 of 4 treatments. The 4 treatments consisted of diets based on dry-rolled corn (**DRC**) with 25% corn-based WDGS and coarsely (~2.45- to 3.81-cm chop length) ground AH, replacing corn at 2% (**AH-2**), 6% (**AH-6**), 10% (**AH-10**), and 14% (**AH-14**) of dietary DM. Soybean meal, Rumensin (33 mg/kg; Elanco Animal Health, Greenfield, IN), limestone, vitamins, and minerals were incorporated into a supplemental premix and fed at 3.24% of DM. The WDGS used in the experiment was delivered weekly from a single source (Abengoa Bioenergy, York, NE) and stored on a concrete pad. Samples were collected weekly and any time a new load was delivered, changes in DM were monitored.

Feedbunks were evaluated visually each day of the experiment at ~0730 h to determine the quantity of feed to offer each animal. The bunk management approach was designed to allow for 0.25 to 0.50 kg of feed remaining in the feedbunk at time of evaluation. After the quantity of feed to be provided to each bunk was determined, a batch of each diet sufficient to supply the feed for all pens on a given treatment was mixed in the feed truck (Roto-Mix 8760 (Roto-Mix, Dodge City, KS.), scale readability ± 0.09 kg) for ~5 min. Cleanout of the feed truck was monitored to ensure that cross contamination of diets was minimized. Steers were fed once daily throughout the experiment, starting at ~0800 h. Cattle were individually weighed before feeding on d 0, 1, 35, 70, 105, 140, 174, and 175.

Carcass Evaluation

At the end of the feeding period, steers were shipped to a commercial abattoir for harvest. Chilled carcasses were evaluated with the VBG2000 (Vision For You, L.L.C., Dakota Dunes, SD) beef carcass grading camera (Shackelford et al., 2003). Individual carcass data, including HCW, marbling score, quality grade, vision yield grade, adjusted fat thickness, and LM area, were assessed. Quality grade was determined from the marbling score and maturity data.

Laboratory Analyses

Samples of each diet were taken daily and frozen, and composited over a 7-d period. Feed refusals were measured weekly. Diet and ort samples were analyzed for DM by oven drying at 55°C to constant weight. Diet samples were then ground with a Wiley Mill (Arthur Thomas Co., Philadelphia, PA), fitted with a 1-mm screen. The NDF content was determined by placing the diet sample in an individual Ankom fiber bag (F57 Filter Bags, Ankom Technology, Macedon, NY) that was heat sealed. The NDF analysis was performed with

Table 1. Composition and analyzed nutrient content (DM basis) of dry-rolled corn-based diets with 25% wet distillers grains with solubles and 2%, 6%, 10%, or 14% alfalfa hay[1]

	Treatment			
Item	AH-2	AH-6	AH-10	AH-14
Ingredient, %				
Dry-rolled corn	68.81	64.94	61.07	57.20
WDGS[2]	25.00	25.00	25.00	25.00
Alfalfa hay	2.00	6.00	10.00	14.00
Urea	0.95	0.82	0.69	0.56
Supplement[3]	3.24	3.24	3.24	3.24
Analyzed composition, %				
DM	66.69	65.61	65.19	65.34
CP	18.40	18.10	18.40	19.0
NDF	14.35	15.40	18.11	20.31
Ether extract	5.9	5.4	5.5	5.2
Ash	5.2	4.8	4.3	4.2
Ca	0.71	0.65	0.64	0.74
P	0.49	0.49	0.44	0.50
S	0.28	0.30	0.31	0.31

[1]Diets were based on dry-rolled corn with 25% wet distillers grains and solubles with alfalfa hay concentrations of 2% (AH-2), 6% (AH-6), 10% (AH-10), and 14% (AH-14) of dietary DM.

[2]WDGS = wet distillers grains with solubles. The average DM content of WDGS during the experiment was 35.61% and WDGS was produced solely from corn grain.

[3]Rumensin (Elanco Animal Health, Greenfield, IN) and vitamins and minerals to meet or exceed NRC (1996) requirements were incorporated into a commercial supplement premix.

an Ankom 200 Fiber Analyzer (Ankom Technology), using the procedures of Van Soest et al. (1991). Heat-stable α-amylase and sodium sulfite (1 g/100 mL of NDF solution) were added to the solution during the analysis. Bags containing the residual were then dried for 24 h at 100°C in a forced-air oven for quantification of the NDF residue. The remainder of the diet analyses [CP, ether extract (**EE**), ash, Ca, P, S] were completed at a commercial laboratory (Servi-Tech Lab, Hastings, NE). Crude protein was determined using the Kjeldahl method. Ether extract was quantified by refluxing ether over samples in Soxhlet tubes for 18 h. Calcium, P, and S were determined using atomic absorption after a nitric-acid, perchloric-acid digestion.

Calculations and Statistical Analyses

The G:F was calculated as the quotient of gain divided by intake. All data in the feeding study were analyzed, with steer as the experimental unit in a completely randomized design, using the Mixed Procedure (SAS Inst. Inc., Cary, NC), where preplanned orthogonal contrast statements were used to separate linear and quadratic effects of AH inclusion in the diet. The proportion of cattle in each treatment grading USDA Choice or greater was analyzed as a binomial proportion, using the GLIMMIX procedure of SAS; the model was the same as the other performance data, with the same orthogonal contrasts as previously described to evaluate treatment responses. Effects were considered significant at P-values < 0.05, with tendencies declared at P-values between 0.05 and 0.10.

RESULTS AND DISCUSSION

Diet Analyses

Chemical compositions of the dietary treatments are presented in Table 1. Diets were formulated for equivalent EE concentration and the resulting range across treatments was 5.2 to 5.9% (DM basis). Because of the increased CP concentration of WDGS, our diets were not isonitrogenous, but they were formulated for equivalent degradable intake protein (**DIP**) level of 8.0% of DM. Furthermore, the NDF concentration of diets increased as AH increased in the diet from 2 to 14%, reflecting the greater NDF concentration in AH than in corn. As expected, the S concentration of the diets was very similar (Table 1) and <0.35% maximum tolerable value for cattle fed concentrate diets reported in NRC (2005).

Animal Performance

Alfalfa hay concentration in the diet did not have a linear (P = 0.28) or quadratic (P = 0.68) effect on initial (nonshrunk) BW, as presented in Table 2. Final BW had a tendency to respond in a quadratic (P = 0.07) manner, where final (nonshrunk) BW increased from 2 to 6% AH inclusion but decreased from 6 to 14% AH.

In the current study, a quadratic effect was observed for ADG from d 0 to 35, d 0 to 70, and d 0 to end ($P \leq$ 0.02), in which ADG increased as AH increased from 2 to 6% yet decreased as AH increased from 6 to 14% in the diet. Additionally, from d 0 to 105 and d 0 to 150, ADG also responded quadratically (P < 0.03), where BW gain was increased from 2 to 10% AH inclusion and decreased thereafter.

In contrast, May et al. (2011) fed steam-flaked corn-(**SFC**) based diets with 7.5, 10, and 12.5% AH, with 15% or 30% WDGS and a non-WDGS control that contained 10% AH. There was a linear effect of AH on ADG early in the feeding period (d 0 to 35 and d 0 to 70) with diets containing less AH, resulting in greater ADG (May et al., 2011). In a study where distillers grains were not fed, Hales et al. (2010) fed cattle SFC-based diets with a bulk density of 335 or 386 g/L, and a roughage concentration of 6% or 10% AH, and reported that ADG tended to be greater for cattle fed 10 vs. 6% AH early in

Table 2. Effects of roughage level in dry-rolled corn-based diets with wet distillers grains and solubles (WDGS) on feedlot performance in MARC II finishing steers

Item	Treatment[1]				SEM[2]	Linear[3] *P*-value	Quadratic[3] *P*-value
	AH-2	AH-6	AH-10	AH-14			
Steers, *n*	32	32	32	32	–	–	–
BW, kg							
Initial	341.8	342.9	337.5	333.2	6.51	0.28	0.68
Final	617.8	636.9	622.8	603.2	10.86	0.23	0.07
ADG, kg							
d 0 to 35	1.86	2.04	1.88	1.78	0.062	0.15	0.02
d 0 to 70	1.74	1.88	1.83	1.66	0.055	0.21	<0.01
d 0 to 105	1.67	1.70	1.75	1.58	0.048	0.22	0.02
d 0 to 150	1.49	1.55	1.58	1.48	0.044	0.98	0.03
d 0 to end	1.52	1.62	1.57	1.48	0.046	0.38	0.01
Daily DMI, kg							
d 0 to 35	8.24	8.65	8.99	8.96	0.197	<0.01	0.24
d 0 to 70	8.99	9.59	9.70	9.83	0.191	<0.01	0.22
d 0 to 105	8.73	9.60	10.17	9.45	0.232	<0.01	<0.01
d 0 to 150	9.46	10.12	10.04	10.08	0.271	0.15	0.25
d 0 to end	9.24	9.82	9.93	9.84	0.189	0.02	0.07
G:F, kg/kg							
d 0 to 35	0.225	0.237	0.209	0.199	0.0057	<0.01	0.07
d 0 to 70	0.193	0.196	0.189	0.170	0.0041	<0.01	<0.01
d 0 to 105	0.191	0.179	0.172	0.167	0.0033	<0.01	0.17
d 0 to 150	0.158	0.156	0.158	0.150	0.0034	0.14	0.41
d 0 to end	0.163	0.165	0.157	0.152	0.0031	<0.01	0.23

[1]Diets were based on dry-rolled corn with 25% wet distillers grains and solubles with alfalfa hay concentrations of 2% (AH-2), 6% (AH-6), 10% (AH-10), and 14% (AH-14) of dietary DM.

[2]Pooled SE of least squares mean.

[3]Observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of alfalfa hay.

the feeding period (d 0 to 35). Kreikemeier et al. (1990) fed cattle steam-flaked, wheat-based diets with 0%, 5%, 10%, and 15% AH, and reported that ADG responded quadratically, in which ADG was maximized between 5% and 10% AH inclusion. Corrigan et al. (2009) noted a quadratic response in ADG when feeding 0%, 15%, 27.5%, or 40% WDGS in SFC-based diets, in which 40% WDGS decreased cattle performance compared with other treatments. Depenbusch et al. (2009) fed diets including 15% sorghum distillers grains (wet or dry) with 0% and 6% AH, and observed that cattle fed diets without roughage had decreased ADG. Quinn et al. (2011) reported that cattle fed 15% or 30% WDGS with AH as the roughage source had decreased ADG from d 0 to 105 and d 0 to end, compared with the average of cattle fed coastal bermudagrass hay or sorghum silage as the roughage source. Conversely, Benton et al. (2007) reported no differences among treatments when feeding DRC-based diets containing 30% WDGS, where differing roughage sources (AH, corn silage, and corn stalks) were replaced on an equivalent roughage NDF basis. Uwituze et al. (2010) noted no differences in ADG as a result of roughage source in diets containing 25% dried distillers grains, with corn silage or AH as the roughage source.

In the present study, increasing roughage inclusion level resulted in a linear increase ($P < 0.01$) in daily DMI from d 0 to 35, d 0 to 70, and d 0 to end. The reason for the increased DMI in the diets with the greater concentrations of roughage is likely an energy dilution effect, in which cattle increase DMI in an attempt to maintain energy intake, as proposed by Galyean and Defoor (2003). From d 0 to 105, DMI had a quadratic effect ($P < 0.01$), where an increase in DMI was observed when AH was increased from 2 to 10%, and then DMI decreased from 10 to 14% AH inclusion. This result was somewhat unexpected; an increase from 10 to 14% AH was expected because of the energy dilution phenomenon, which generally occurs at increased roughage concentrations in finishing diets. Recent studies have also evaluated the effect of roughage concentration and source in diets with 15% or 30% WDGS (May et al., 2011; Quinn et al., 2011). May et al. (2011) noted throughout the overall feeding period, DMI had a tendency to increase linearly as AH concentration increased in the diet, which agrees with the data from the current study. Depenbusch et al. (2009) fed diets including 15% sorghum distillers grains (wet or dry) with

Table 3. Effects of roughage level in dry-rolled corn-based diets with wet distillers grains and solubles on carcass characteristics in MARC II finishing steers

	Treatment[1]						
Item	AH-2	AH-6	AH-10	AH-14	SEM[2]	Linear[3] *P*-value	Quadratic[3] *P*-value
Steers, *n*	32	32	32	32	–	–	–
HCW, kg	380.9	387.1	380.6	378.8	7.14	0.69	0.57
Dressing percent	61.36	60.55	60.87	62.47	0.504	0.10	0.02
LM area, cm^2	89.4	86.7	88.3	90.5	1.51	0.47	0.10
Adjusted 12th rib fat, cm	1.11	1.27	1.21	1.06	0.075	0.45	0.01
Yield grade	3.10	3.26	3.19	3.05	0.063	0.44	0.01
Marbling score	423.3	423.4	416.2	424.8	11.11	0.96	0.70
USDA choice, %	56.67	63.33	71.87	54.84	1.724	0.92	0.18

[1]Diets were based on dry-rolled corn with 25% wet distillers grains and solubles with alfalfa hay concentrations of 2% (AH-2), 6% (AH-6), 10% (AH-10), and 14% (AH-14) of dietary DM.

[2]Pooled SEM.

[3]Observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of alfalfa hay.

0% and 6% AH, and observed that decreasing roughage in the diet decreased DMI. As a consequence of decreased DMI, the roughage value of 15% sorghum distillers grains was not adequate to allow for complete roughage removal. Our findings are consistent with the effects of increasing roughage concentration in finishing cattle diets reported by Kreikemeier et al. (1990), Defoor et al. (2002), and Miller et al. (2009), which jointly suggest that the response of changes in dietary roughage concentration is similar to traditional finishing diets, based solely on processed grain when distillers products are included at up to 30% of DM (Galyean and Hubbert, 2012). Conversely, Benton et al. (2007) noted no differences in DMI across differing roughage sources in diets based on a mixture of dry-rolled and high-moisture corn. Uwituze et al. (2010) reported increased DMI in heifers fed corn silage compared with those fed AH in finishing diets, based on SFC and with 25% dried distillers grains. Across roughage inclusion, Quinn et al. (2011) reported no differences in DMI when evaluating 15% or 30% AH, sorghum silage, or coastal bermudagrass hay in SFC diets with 15% or 30% WDGS, and a control without WDGS. Perhaps the increase in DMI associated with an increased AH concentration observed in the current experiment was caused by an energy dilution effect, where cattle increased DMI in an attempt to maintain energy intake equilibrium.

Gain-to-feed ratio from d 0 to 35 responded linearly ($P < 0.01$), in which G:F increased when AH was increased from 2% to 6% and then decreased when AH was increased from 6% to 14% in the diet. Another linear response ($P < 0.01$) was detected for G:F from d 0 to 105, where G:F decreased as AH increased in the diet from 2% to 14% inclusion. For overall G:F (d 0 to end; $P < 0.01$), there was a linear response in that G:F increased from 2% to 6% AH and decreased from 6% to 14% inclusion. Quinn et al. (2011) reported that cattle fed diets based on SFC, including distillers grains and sorghum silage as the roughage source, rather than bermudagrass hay, had a decreased G:F from d 0 to 70 and from d 0 to end, even though diets were balanced on an equivalent NDF content basis. They hypothesized that when cattle were fed sorghum silage as the roughage source, physical factors associated with digesta, such as particle density, ruminal stratification, and particle passage, had a role in decreased G:F (Quinn et al., 2011). Mader et al. (1993) evaluated corn silage and AH in DRC or ground, high-moisture corn finishing diets and noted that steers fed corn silage had greater ADG and G:F than those fed AH; however, an interaction was detected for roughage source and grain type (DRC or ground, high-moisture corn). Hales et al. (2010) fed varying bulk densities of SFC with 6% or 10% AH in a finishing cattle diet without distillers grains and reported that feeding a reduced concentration of roughage tended to improve overall G:F.

The relationship between ADG and AH concentration was described by the equation:

$$AH = f\ (ADG) = (-0.00284 \pm 0.0011)\ x^2 + (0.04174 \pm 0.0185)\ x + (1.44964 \pm 0.0625)$$

with $R^2 = 0.05$. Solving the first derivative indicated that the optimal concentration of roughage (AH in this case) in a finishing diet, based on DRC with 25% WDGS, was 7.34% for maximum ADG. The optimal ADG at 7.34% roughage inclusion is partially a result of the tendency for increased final BW (Table 2) at 6% and 10% AH inclusion. Furthermore, the optimal concentration is closer to 6% than 10% AH inclusion, because the cattle fed diets including 6% AH had less DMI than cattle fed 10% AH.

The relationship between G:F and AH concentration was described by the equation:

$$AH = f\ (G{:}F) = (-0.00011 \pm 0.00009)\ x^2 + (0.00068 \pm 0.00152)\ x + (0.1636 \pm 0.00512)$$

with $R^2 = 0.10$. Solving the first derivative indicated that the optimal concentration of roughage (AH in this case) in a finishing diet, based on DRC with 25% WDGS, was 3.12% for maximum G:F. Based on the results of the first derivative, the improvement in G:F at decreased concentrations of AH is due, in part, to a decreased DMI that was observed when reduced concentrations (2% and 6%) of AH were fed. The decrease in DMI at decreased concentrations of AH was probably the result of an energy dilution effect, in which cattle eat less when diets contain more concentrate and less roughage.

Carcass Characteristics

The concentration of AH in the diet had no effect ($P > 0.51$) on HCW, LM area, marbling score, or proportion of cattle grading choice or greater as presented in Table 3. Conversely, Quinn et al. (2011) reported decreased HCW for cattle fed AH compared with the average of cattle fed bermudagrass hay or sorghum silage as the roughage source in diets containing WDGS. In the current study, dressing percentage (**DP**) responded quadratically ($P = 0.02$), in which it decreased from 2 to 10% AH inclusion and increased thereafter to 14%. In contrast, Quinn et al. (2011) and Uwituze et al. (2010) reported no differences in DP among treatments. In the present study, a quadratic response ($P = 0.01$) was detected for adjusted 12th rib fat and yield grade, which increased from 2 to 6% AH inclusion in the diet and then decreased as AH was increased to 14%. The increase in 12th rib fat and yield grade at lower concentrations of AH likely represents the increase in the amount of starch in the diet, because AH was replaced with DRC. Our data are inconsistent with the results of Quinn et al. (2011), in which no differences were observed in 12th rib fat; however, their experiment was designed to evaluate the use of different roughage sources included on an equivalent NDF basis. May et al. (2011) also observed no differences in 12th rib fat. Furthermore, May et al. (2011) noted no differences in HCW, DP, LM area, and the proportion of cattle grading Choice or greater, when cattle were fed 15% or 30% WDGS, with 7.5%, 10%, or 12.5% AH in SFC-based diets.

Conclusion

Results indicate that decreasing AH to 2% in a finishing diet, based on DRC with WDGS, may decrease ADG but does decrease DMI, which results in an increased G:F, whereas feeding AH at 6% in a finishing diet seems to optimize ADG and G:F, and only slightly increases DMI. As a result of solving for the first derivative, AH inclusion of 3% and 7% optimize G:F and ADG, respectively. The current feedlot industry standard for roughage inclusion in finishing cattle diets is 8 to 9% of DM; however, our data suggest that the ideal roughage inclusion for finishing diets, based on DRC with WDGS, is 3% for optimal G:F and 7% for optimal ADG.

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